

# Tunability of the reflection and the transmission spectra of two periodically corrugated metallic plates, obtained by control of the interactions between plasmonic and photonic modes

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## Abstract

We theoretically study the interactions between plasmonic and photonic modes within a structure that is composed of two thin corrugated metallic plates, embedded in air. We show that the interactions depend upon the symmetry of the interacting modes. This observation is explained by the phase difference between the Fourier components of the two gratings. The phase can be controlled by laterally shifting one grating with respect to the other. Therefore, this relative shift provides an efficient “knob” that allows to control the interaction between the various modes, resulting in an efficient modulation of light transmission and reflection in the proposed structure. Based on this concept we show that the investigated structure can be used as tunable plasmonic filter.

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## I. INTRODUCTION

The field of surface plasmon polaritons (SPPs) [1] is rapidly developing over the last couple of decades. One of the active plasmonic related research topics is the waveguiding characteristics of multilayered plasmonic structures [2]. A basic example for such a structure is that of a thin metal film sandwiched between two dielectric (insulating) media (IMI). For a thin enough film, the SPP modes guided by the two dielectric-metal interfaces are coupled through the metal, thus creating supermodes that exhibit a dispersion varying with metal thickness. A variant of the IMI structure that has been studied recently is a doubly corrugated metallic layer which was analyzed for sinusoidal [3,4] and rectangular [5,6] gratings, with possible applications for a band-gap plasmonic laser and optical filters. A more complex multilayered configuration is the double metal plate structure, comprising of an insulator/metal/insulator/metal/insulator (IMIMI) interface. The dispersion equations and the waveguiding characteristics of this configuration have been studied by [7-9]. This structure was recently applied for the calculation of the optical forces between the metallic plates [10]. In this paper, we study a symmetric one-dimensional IMIMI structure, of which each of the two metallic layers is periodically corrugated. We analyze this configuration and show that the relative shift between the corrugated interfaces controls the interaction between the modes supported by the structure. Furthermore, we demonstrate that the control of these interactions enables tunable filtering properties of both the reflection and the transmission spectra. The computer simulations used for this study are based on the Rigorous Coupled Wave Analysis (RCWA) method, also known as the Fourier Modal Method (FMM). We apply the factorization rules that lead to faster convergence for TM polarization [11-14]. The paper is structured as follows. In Section 2, the modes supported by the structure are described and classified into groups. In Section 3, it is demonstrated how the interactions between the plasmonic and the photonic modes form an effective "absorption gap", both under normal and oblique incidence. In Section 4, we show how the shift in absorbance lines, can be utilized to obtain tunable filtering properties of the reflection and transmission spectra. Furthermore, we show (to our knowledge for the first time) how the poor transmission can be enhanced by introducing a large refractive index contrast between the substrate/superstrate and the air gap separating between the metallic plates.

## II. MODES OF AN IMIMI STRUCTURE

Fig. 1(a) shows a flat double plate structure, with metal layer thickness  $H_M$  and dielectric gap between the plates  $H_A$ . As previously analyzed [7-10], a symmetric double metal plate supports four plasmonic modes. These modes can be classified as two long range surface plasmon polariton (LRSP) modes which can be either symmetric or anti-symmetric with respect to each other (defined as LRS and LRA) and two short range surface plasmon polariton (SRSP) modes which can also be either symmetric or anti-symmetric with respect to each other (SRS and SRA). Throughout this paper the plane of symmetry is assumed to be in the middle of the dielectric gap  $H_A$  ( $z=0$ ) and the symmetry is defined with regard to the magnetic field  $H_y$ . The characteristic equation for the symmetric plasmonic modes in a symmetric IMIMI structure embedded in a uniform dielectric media is given by:

$$\tanh(k_D H_A/2) = -\frac{\frac{k_D k_M}{\varepsilon_D k_M} + (k_M/\varepsilon_M)^2 \tanh(k_M H_M)}{\frac{k_D k_M}{\varepsilon_D k_M} + (k_D/\varepsilon_D)^2 \tanh(k_M H_M)} \quad (1)$$

where  $k_i^2 = k_X^2 - \varepsilon_i k_0^2$  is the decay constant along the Z direction and  $i = M, D$  for the metallic and dielectric layers respectively. To obtain the anti-symmetric modes, the term  $\tanh(k_D H_A/2)$  should be replaced with  $\coth(k_D H_A/2)$ . Besides these four modes, the structure also supports Fabry-Perot modes (FPM) with  $k_X=0$  that reside between the two metal plates. Also, guided modes exist within the dielectric gap between the plates. For a not too thin metallic layer thickness, these modes can be approximately regarded as the TM metallic slab waveguide. As will be shown, the FPM and the TM guided modes have an important role when considering potential applications of the investigated structure. Next we add a rectangular grating modulation with grating depth of  $H_G$  (either outwards or inwards, see Fig 1. (b) and (c)). Thus, the permittivity function takes the form:  $\varepsilon(x) = \sum_{h=-\infty}^{\infty} \varepsilon_h \exp(j2\pi h x/L)$  where  $L$  is the grating period. The Fourier components of the permittivity function are given by:

$$\varepsilon_h = [(\varepsilon_M - \varepsilon_D) \times \sin(\pi h d/L)/(\pi h)] \times \exp(j2\pi h S/L) \quad (2)$$

Where  $d/L$  is the duty cycle of the metallic ridge and  $S$  is the relative shift between the two gratings. Under normally incident illumination, the allowed k-vectors of the modes take discrete values of the multiples of the grating vector  $K$  ( $K=2\pi/L$ ).

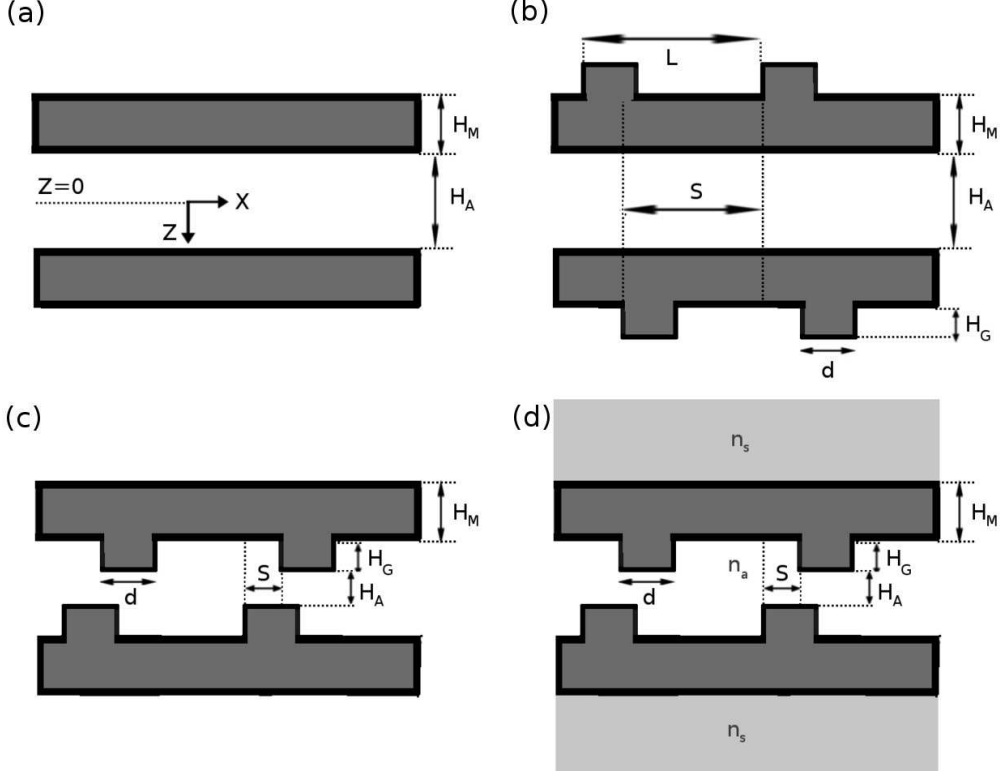


Figure 1. Schematic drawing of an IMIMI structure. (a) flat interfaces. (b) "outwards" grating modulation. (c) "inwards" grating modulation. (d) non-homogeneous dielectric environment with "inwards" grating modulation.

### III. MODE COUPLING AND INTERACTION

A 1D periodic structure has a bandgap which resides at the edges of the Brillouin Zone. It was shown that for a periodic structure with grating vector  $1K$ , no bandgaps are formed at normal incidence ( $k_X=0$ ), unless the grating has an additional  $2K$  Fourier component [3]. As can be observed from Eq. 2, for the specific case of  $d/L=0.5$ , the even Fourier terms vanish and thus no  $2K$  components exist. Therefore, for such a case no bandgaps should be formed at normal incidence. This issue and its consequences will be addressed again in Section 4. When considering a double plate structure in which each of the plates is modulated by a grating (Fig 1(b) and (c)), an additional "gap" mechanism arises. This "gap" is due to mode conversion as a result of phase matching between two distinct modes. The phase matching is highly dependent on the mode symmetry as will be shown immediately. This mode conversion mechanism can be explained by the Coupled Mode Theory [15,16]

and is well known in photonic structures [17, 18]. It was also observed in an adiabatically varying plasmonic structure [19], and by the interaction between a waveguide mode and a plasmonic mode [20].

### A. Weak interaction between symmetric and anti-symmetric modes

To demonstrate the above, we investigated a double plate structure of the type shown in Fig. 1(b) with the parameters  $H_G=80$  nm,  $H_M=30$  nm,  $L=1000$  nm and  $d/L=0.75$ . The materials are assumed to be air and Ag, i.e.  $\varepsilon_D=1$  and  $\varepsilon_M$  is defined by the Drude model  $\varepsilon(\omega) = \varepsilon_\infty - (\varepsilon_0 - \varepsilon_\infty) \times \omega_P^2 / (\omega^2 + i\omega\gamma)$  with the following parameters:  $\varepsilon_\infty=4.017$ ,  $\varepsilon_0=4.896$ ,  $\omega_P=1.419 \times 10^{16}$  rad/sec,  $\gamma=1.117 \times 10^{14}$  rad/sec. In Fig. 2, the calculated absorption of this structure under normally incident TM plane wave illumination is plotted for three different values of  $S/L$  as a function of the incident wavelength and the separation distance  $H_A$ . The absorption (Ab) is calculated by the RCWA algorithm using the relation  $\text{Ab}=1-\text{T}-\text{R}$  where T and R are the total transmission and reflection diffraction efficiencies respectively. In the absence of absorption,  $\text{T}+\text{R}=1$ . Three different modes can be observed, designated as A, B and C. Mode A is the SRS mode. Mode B is the first order FPM and is therefore anti-symmetric with regard to the magnetic field inside the air gap between the plates. Mode C is an anti-symmetric guided mode. This mode is not a solution of the characteristic equations of the non-modulated IMIMI structure (Eq.1), and can be approximated as the slab  $TM_1$  mode. The condition for exciting this mode is  $L=m\lambda_0/n_{eff}$  where m is an integer and  $n_{eff}$  is the effective index of the mode, which is smaller than one for the wavelengths calculated in Fig. 2.

Thus wavelengths smaller than the period of the grating ( $1 \mu\text{m}$ ) excite this mode. Fig. 3 shows the magnetic field distribution of the three modes, calculated for a vacuum wavelength of 600 nm. It can be seen that the SRS mode has an effective wavelength of  $L/2$  (Fig. 3(a)), whereas the FPM (Fig. 3(b)) is invariant along the x-axis, indicating the absence of a  $k_x$  component. Fig. 3(c) shows that the effective wavelength of the  $TM_1$  slab mode occupies a single unit cell indicating that the effective index is smaller than 1 (the unit cell is larger than the vacuum wavelength). To conclude, all three modes have different  $k_X$ -vectors: for mode A  $k_X=2K$ , for B  $k_X=0K$  and for C  $k_X=1K$ . In all three insets of Fig. 2 mode A intersects with modes B and C. However, the intersections result in different interactions in the three

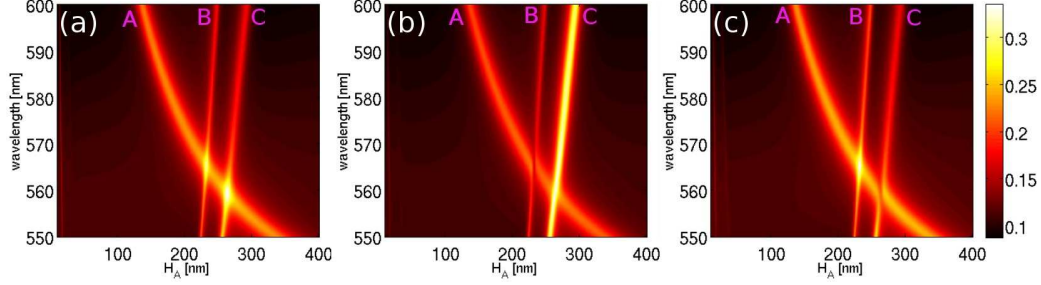


Figure 2. Absorption as a function of the incident wavelength and  $H_A$  for three different relative shifts between the metal plates for the case of outwards pointing gratings as shown in Fig. 1(b). (a)  $S/L=0$  (b)  $S/L=0.25$  (c)  $S/L=0.5$ .

| $S/L$ | $\Phi(0K)$ | $\Phi(1K)$ | $\Phi(2K)$ | $A \leftrightarrow B$ ( $2K \leftrightarrow 0K$ ) | $A \leftrightarrow C$ ( $2K \leftrightarrow 1K$ ) |
|-------|------------|------------|------------|---|---|
| 0     | 0          | 0          | 0          | no PM   | no PM   |
| 0.25  | 0          | $\pi/2$    | $\pi$      | PM  | partial PM  |
| 0.5   | 0          | $\pi$      | 0          | no PM   | PM  |

Table I. Phases of the three modes and phase matching between the different modes for three values of relative grating shift. PM stands for phase matching

considered cases. In Fig. 2(a) there is no interaction between the different modes and the absorption at the intersection of the A-B and A-C modes is simply the summation of the absorption of the two relevant modes. Moreover, the modes do not alter their characteristics at the intersection region or in its surrounding. In Fig. 2(b), one can observe an interaction between the modes, in the form of mode conversion at the A-B intersection. This results in an anti-crossing between modes A and B. The A-C intersection is kept unchanged, i.e. no interaction between these two modes is observed. Fig. 2(c) shows the opposite scenario, where the A-B modes are not interacting whereas anti-crossing is observed around the A-C intersection. Let us now describe the mechanism that is affecting the interaction between the modes. Due to the fact that mode A is symmetric with  $k_X=2K$  while mode B is anti-symmetric with  $k_X=0K$ , the phase matching that allows the  $A \leftrightarrow B$  transition to occur, involves interaction with the  $2K$  grating component (more generally, other interactions, e.g.  $0K_{FPM} + 2K_{SRS} = 3K - 1K$  might be possible as well, but are weaker than the "straightforward"  $0K_{FPM} + 2K_{SRS} = 2K$  interaction, and are therefore not considered). In Table 1, the values

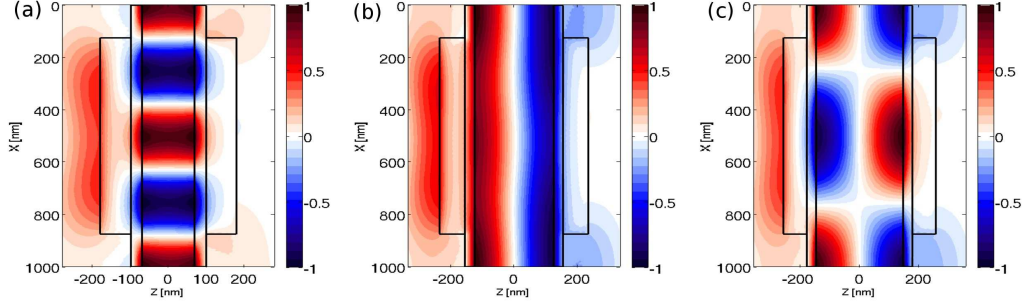


Figure 3. Normalized real part of the magnetic field distribution ( $H_y$ ) calculated at  $\lambda=600$  nm and  $S/L=0$  for: (a) SRS mode ( $H_A=137.5$  nm). (b) FPM ( $H_A=248.5$  nm). (c)  $TM_1$  mode ( $H_A=293$  nm). The square rectangles define the boundaries of the metallic grating ridges and the metallic plates.

of the phase  $\Phi$  ( $\Phi(hK)$  is the phase of the  $h$ th Fourier component, as calculated from Eq. 2) are summarized for the three different values of  $S/L$  that were considered in Fig. 2. First, we consider the  $A \leftrightarrow B$  transition. As modes A and B are of opposite symmetry, no interaction is possible unless they undergo a relative phase shift of  $\pi$  with respect to the mirror plane  $z=0$ . This is similar to the condition for coupling of symmetric and anti-symmetric modes in photonic grating couplers (see e.g. [18]). For  $S/L=0$ , this condition can not be satisfied. In this case the gratings have no phase difference with respect to each other and therefore the necessary  $\pi$  phase shift can not be provided. However, for  $S/L=0.25$ ,  $\Phi(2K)$  undergoes a  $\pi$  phase shift. This explains the anti-crossing in Fig. 2(b). For  $S/L=0.5$ ,  $\Phi(2K)$  has again the same phase as for  $S/L=0$ . Therefore, no anti-crossing is seen in Fig. 2(c). For the  $A \leftrightarrow C$  transition, the considerations are similar, only now the interaction is provided by the  $1K$  component. Again, for  $S/L=0$ , no interaction is possible, as the A and C modes have opposite symmetry. As shown in Table 1, the interacting grating component (i.e.  $1K$ ) undergoes a  $\pi$  phase shift for  $S/L=0.5$ . Therefore, for these modes we see an anti-crossing in Fig. 2(c). In Fig. 2(b), only a partial phase match (phase difference of  $\pi/2$ ) is obtained for the  $A \leftrightarrow C$  transition, and no clear anti-crossing can be observed.

## B. Strong interaction between modes of the same symmetry

When the gratings are pointing "outwards" (with regard to the dielectric region between the two metal plates) as in the previously described case, the anti-crossings observed in Fig. 2 are generally weak. This is because the interactions between the modes occur mostly in the dielectric region between the plates, while the gratings are placed in the opposite sides of the metal plates. Now we consider the case where the gratings are pointing inwards as shown in Fig.1 (c). The structural parameters are identical to the previously discussed structure, (subsection 3.1) besides that  $H_G=30$  nm, with the gratings extending into the dielectric gap between the plates. The absorption curves of this structure are plotted in Fig. 4(a)-(c), for three different values of  $S/L$ . Fig. 4(d) shows schematically the curves of the original unperturbed modes as they would approximately exist without inter-modal interaction, superimposed on the  $S/L=0$  case (also shown in Fig. 4(a)). These unperturbed modes are marked by the green, blue and white lines. As in the previous simpler case, we have three modes A, B and C which are the SRSPP modes, FPM, and waveguide modes (WGM), respectively, where the subscripts denote the symmetry. In this example we are considering a larger domain both in wavelength and in separation between the plates. As a result, we can now observe both symmetries of the three modes. In Fig. 4(d),  $A_A$  and  $A_S$  represent the SRA and SRS modes respectively. As expected, these two modes can be seen to have the same characteristics in the limit of  $H_A \rightarrow \infty$  as the two IMI modes have no interaction.  $B_A$  and  $B_S$  are the first and second order FPM respectively, having opposite symmetry.  $C_A$  and  $C_S$  are WGM ( $TM_1$  and  $TM_2$  respectively). As before, the K vectors of the SRSPP, FPM and WGM are  $2K$ ,  $0K$  and  $1K$ , respectively. In Fig. 4(a), we can observe the interactions  $A_A \leftrightarrow B_A$ ,  $A_S \leftrightarrow B_S$  and  $A_A \leftrightarrow C_A$  as expected, since only interactions between modes of the same symmetry are allowed. The  $A_S \leftrightarrow C_S$  interaction cannot be observed. The absence of this transition may be explained by the strong  $A_S \leftrightarrow B_S$  transition, masking other interactions. In Fig. 4(b) the  $2K$  interactions of opposite symmetry are allowed. Therefore we see the  $A_S \leftrightarrow B_A$  and  $A_A \leftrightarrow B_S$  interactions. We also identify interactions involving the  $1K$  component between modes of the same symmetry, because the  $1K$  component is partially matched (i.e.  $A_A \leftrightarrow C_A$  and also  $A_S \leftrightarrow C_S$  which in contrary to Fig. 4(a) is now visible as it is not masked by the  $A_S \leftrightarrow B_S$  interaction which is now forbidden). In Fig. 4(c) we see interactions between modes of opposite symmetry due to the  $1K$  component ( $A_S \leftrightarrow C_A$ ,



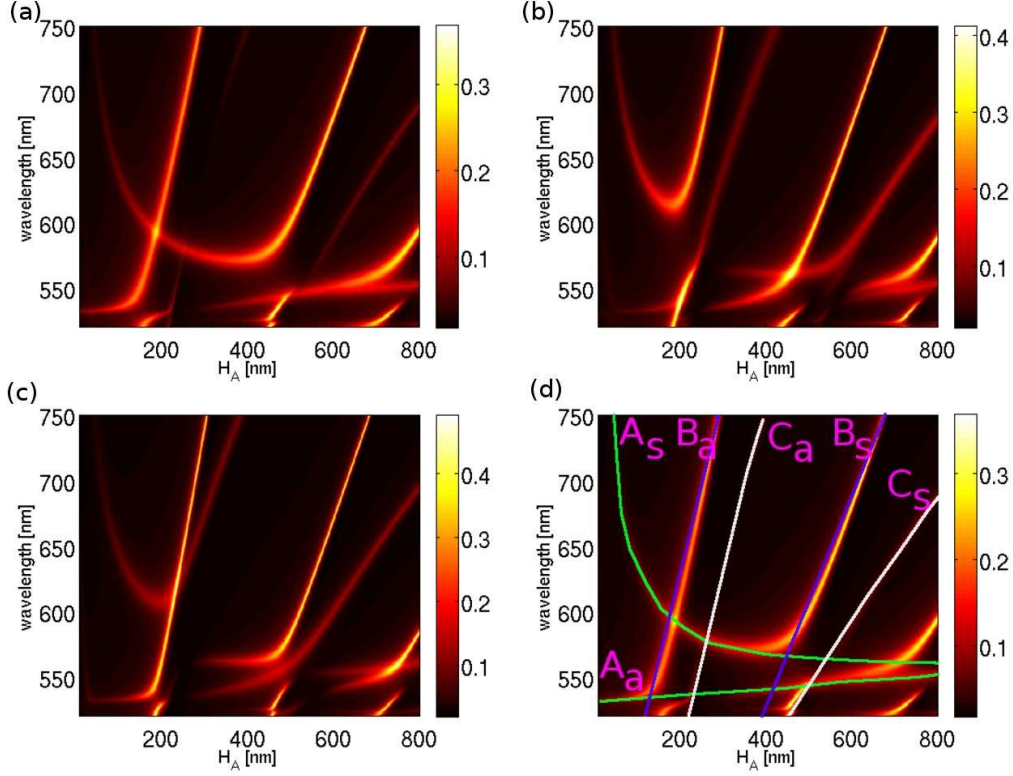


Figure 4. Absorption as a function of the incident wavelength and  $H_A$  for three different relative shifts between the metal plates for the case of inwards pointing gratings as shown in Fig.1(c). (a)  $S/L=0$  (b)  $S/L=0.25$  (c)  $S/L=0.5$ . (d) Schematic drawing of the supported modes as they would approximately appear with no inter-modal interaction. The schematic curves are superimposed on the  $S/L=0$  scenario that is also shown in Fig. 3(a). The green, blue and white lines represent SRSP modes, FPM and WGM respectively (both symmetric and anti-symmetric).

$A_A \leftrightarrow C_S$ ) and continue to see interactions between modes of the same symmetry that are due to the 2K component ( $A_A \leftrightarrow B_A$  and  $A_S \leftrightarrow B_S$ ).

### C. Mode hybridization under oblique incidence

We now consider the effect of changing the angle of incidence. For small oblique incident angles (incident TM plane wave is tilted in the X-Z plane), the above discussed plasmonic modes will have two possible frequencies which solve the SPP characteristic equation (Eq. 1) for a given  $k_X$ . Thus, two branches of the SPP modes originating from  $k_X=0$  appear at a dispersion diagram of the structure. This is in contrast to the FPM mode which

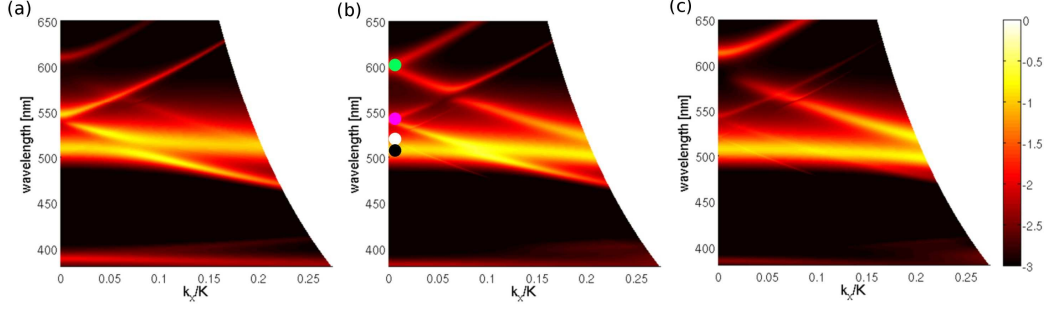


Figure 5. Logarithmic scaled plot of the absorption as function of the incident wavelength and the normalized transverse wavevector  $k_x/K$  for the following three relative shifts: (a)  $S/L=0$  (b)  $S/L=0.25$ . The SRS, SRA, LRS and FPM are designated at  $k_x=0$  with green, purple, white and black dots respectively. (c)  $S/L=0.5$ .

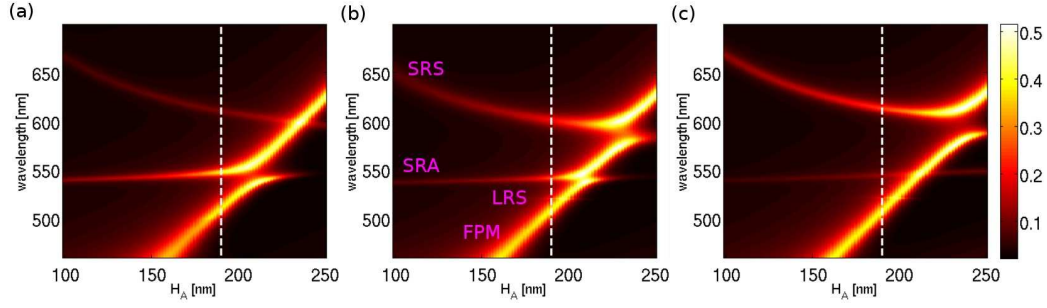


Figure 6. The absorption as function of the incident wavelength and the plate separation under normally incident light for the same structure as for Fig. 5. The white dashed line corresponds to the  $H_A=190$  nm at  $k_x=0$  plotted in Fig. 5. Three relative shifts were considered: (a)  $S/L=0$  (b)  $S/L=0.25$ . (c)  $S/L=0.5$ .

still exhibits a single branch, because the FPM condition for  $k_z$  is uniquely satisfied by an increase of frequency with the increase of the incident angle. As a consequence of the existence of two separate SPP branches, distinct plasmonic modes now intersect at  $k_x \neq 0$ , and may interact with each other. In Fig. 5, a dispersion diagram is plotted for the “inwards” grating structure with the parameters  $H_A=190$  nm,  $H_M=30$  nm,  $H_G=10$  nm,  $L=500$  nm and  $d/L=0.75$ , for three different relative shifts. Now the grating period is halved compared with the previous case and thus the SPP modes have a  $1K$  wavevector and there is no coupling to WGM (the  $1K$  component for  $L=1000$  nm is equivalent to a non existing  $0.5K$  component for  $L=500$  nm). From Figs. 5(a) and 5(c) one can clearly

observe the appearance of a bandgap at  $k_X=0$  for  $S/L=0$  and  $S/L=0.5$ . This bandgap is due to the 2K grating component, as explained in [3,6]. As explained in these references, for  $S/L=0.25$ , the bandgaps disappear. In Fig. 5(b) (where there are no gaps at  $k_X=0$ ), we have marked the excited modes as SRS, SRA, LRS and FPM. The additional LRA mode is very poorly coupled in this specific configuration and is therefore not observed (we have observed that for thicker gratings, coupling to the LRA becomes significant). To help put the current discussion in the context of the previous section, we also plotted the absorption of the same structure for normally incident light as a function of  $H_A$  (see Fig. 6). The data set at  $H_A=190$  nm (see vertical dashed lines in Fig. 6) corresponds to the  $k_X=0$  case in Fig. 5. Next we discuss the interactions between the modes:

**A - Interactions between plasmonic and photonic modes.** The SRA and FPM interact for  $S/L=0$  around  $k_X/K=0.075$ , since both modes have the same symmetry. Because the interaction between the FPM and SPP modes is now obtained through the 1K component, we see that for  $S/L=0.5$  the FPM and SRS are interacting. Both interactions can be also observed for  $S/L=0.25$ . Yet, the interaction strength is weaker, because the phase matching is partial.

**B - Interactions between the plasmonic modes.** The mechanism of interactions between plasmonic modes at a single layer for  $k_X \neq 0$  was analyzed in [21,6], and found to originate from the 2K component. Therefore, we expect that interaction between distinct plasmonic modes will occur if the 2K component will provide the required phase shift to match the symmetry between the plasmonic modes. Thus, interactions between symmetric and anti symmetric modes should be possible only for the case of  $S/L=0.25$ . Indeed, it is seen that for such a shift the SRA and SRS modes are interacting whereas for  $S/L=0$  and  $S/L=0.5$  no interaction between these modes can be observed. The interaction between the LRS and SRS is expected to show an opposite behavior. This is because both modes have the same symmetry and therefore the 2K component must not provide any phase shift. Indeed, interactions are observed for  $S/L=0$  and  $S/L=0.5$  but not for  $S/L=0.25$ .

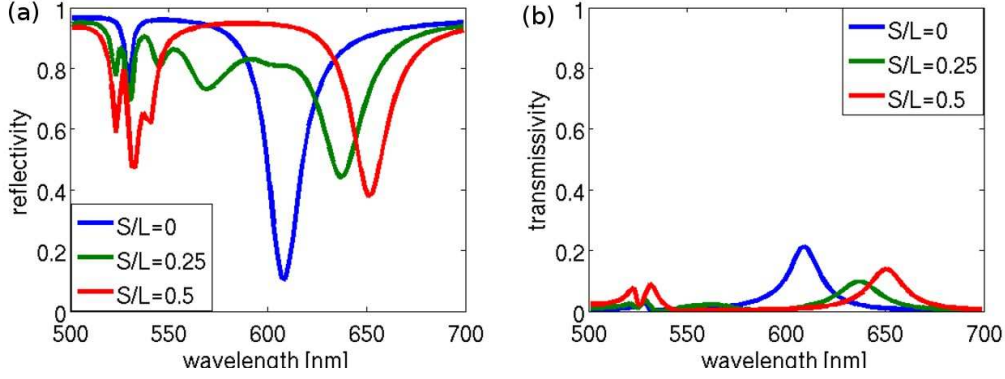


Figure 7. (a) Reflectivity and (b) transmissivity as function of the incident wavelength.

#### IV. TUNABLE FILTERING OBTAINED BY SHIFTING THE RELATIVE GRATING POSITION

One of the potential applications of the investigated structure is a tunable filter, where tuning can be obtained by controlling the relative shift between the two plates. Such a tunable filter has been previously proposed for multilayered dielectric structures [22-24]. Tunable filtering can be obtained for both the transmission and reflection spectra of the structure. However, while the reflection is significant, the transmission is low. We will first consider the case of reflection tunability, and then discuss the modifications needed for obtaining high transmission that is needed for an efficient tunable transmission filter. Let us consider a structure with the following parameters:  $L=500$  nm,  $H_G=30$  nm,  $H_M=30$  nm. We choose  $d/L=0.5$  to maximize the coupling to the SPP modes. As only the 1K component is interacting, the cases of  $S/L=0$  and  $S/L=0.5$  are the two extreme cases (maximal phase difference of  $\pi$  for the 1K component between these two cases). In Fig. 7 the reflection and the transmission as a function of wavelength are plotted for three values of relative shift  $S/L=0$ ,  $S/L=0.25$ , and  $S/L=0.5$ , with separation of  $H_A=196$  nm. For  $S/L=0$  the first order FPM and the SRS do not interact, providing low reflection coefficient of  $R=0.1$  at their crossing point. For  $S/L=0.5$  the modes interact and the reflection increases to  $R=0.9$  at the same wavelength. In addition, one can notice that the resonance dip in reflection is shifted in wavelength. For example, Fig. 7(a) shows a shift of the reflection dip from 608 nm to  $\sim 650$  nm. These effects can be used for the realization of a tunable plasmonic filter. While similar shifts in the wavelength of resonance are also observed for the transmission of light

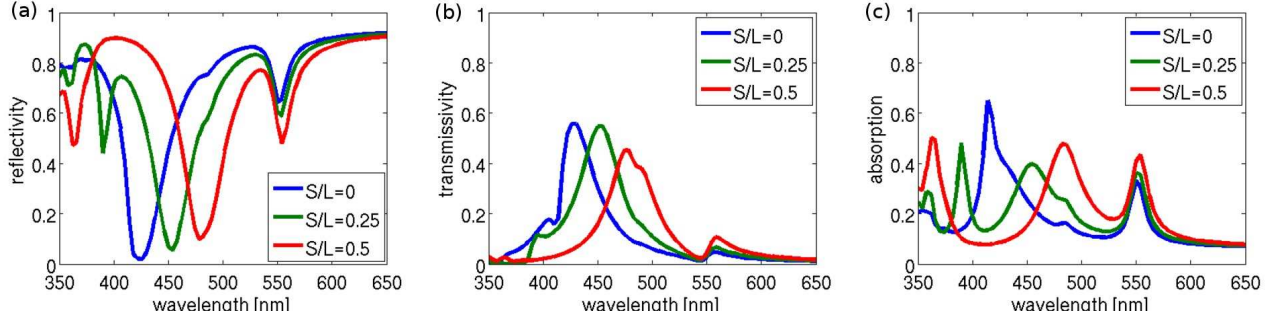


Figure 8. (a) reflectivity (b) transmissivity and (c) absorption as function of the incident wavelength, for the double plate embedded in an inhomogeneous dielectric index configuration

through the investigated structure (Fig. 7(b)), the overall transmission efficiency is seen to be very low. As shown before [25,26], the transmission mechanism is via localized SPP (LSP) modes that reside in the grating ridges, and not through the flat surface SPPs [27]. Therefore, in order to enhance the transmission, it is desirable to confine more energy in the grating ridges, at the expense of lower energy concentration at the flat surfaces. A possible way to achieve this is by changing the substrate and superstrate refractive indices to  $n_S=2.6$  (e.g. by using Silicon Carbide substrate, see Fig. 1(d) for a schematic of the structure). By keeping the metal layers thin ( $\sim 20$  nm) the SPPs on both interfaces remain coupled. The SPPs tend to be more confined in the lower index dielectric interface, and to be more radiating at the higher index dielectric. Thereby, for an “inwards” grating configuration, more energy is confined at the grating ridges that reside near the lower index material (Fig. 8). In Fig. 8 the transmission and reflection spectra are plotted for the following configuration:  $H_A=25$  nm  $H_M=25$  nm and  $H_G=40$  nm. The substrate and the superstrate have a dielectric index of  $n_S=2.6$  and the plates are separated by an air gap ( $n_A=1$ ). It is observed that the transmission efficiency is greatly enhanced. The structure still obtains mirror symmetry around  $Z=0$ , however the plasmonic modes can no longer be identified as LRSP or SRSP as these only exist for the cases for which each plate is embedded in a homogeneous dielectric medium. Still, because of the mirror symmetry, the modes can be classified as symmetric and anti-symmetric modes of the overall structure. It can be seen for the absorption spectra in Fig. 8(c) that an anti-crossing is formed for  $S/L=0.5$ . This anti crossing generates the observed shift in the reflection and transmission peaks seen in Fig. 8 (a) and (b) respectively.

## V. CONCLUSIONS

We study the plasmonic and photonic modes that are supported by an IMIMI structure made of thin metallic layers. It is shown that by adding grating modulation to both metallic layers, the supported modes can interact. This interaction is explained by the symmetry of the modes and the relative phase shift provided by the grating Fourier components. The various interactions are explored both under normally and oblique incident illumination. Finally, we show that a relative lateral shift between the two gratings provides tunable filtering properties. Because of the diversity of the supported modes and their interactions, this structure seems to be of interest for further research, and for investigating additional applications, e.g. the selective excitation of plasmonic modes for plasmonic focusing applications [28,29].

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